

the following: Duration of the 20 volt square wave pulse was 6 milliseconds. The current was measured with a Hewlett Packard model 428B Clip-on D.C. milliammeter connected to one channel of the oscilloscope and found to be 7.5 milliamperes during this 6 millisecond pulse. Thus, energy consumption is about $20 \times 7.5 \times 6 \times 10^{-6} = 10^{-3}$ joules per pulse. If the pump were operated as described in the preceding paragraph (trains of 10 pulses delivering 5 microliters per train), the energy consumption per microliter delivered would be 2×10^{-3} joules. Now a typical one ampere hour mercury cell of the type used in implanted cardiac pacemakers has an energy content of about 4.8×10^3 joules. Assuming half of this energy to be available for useful work, the pump could deliver about one liter from this power source.

If the present system were used to dispense insulin based on a need of 0.15 milliliters per day, it would take 18 years for the present pump to pump one liter. This figure, that is, 18 years, must be diminished by the shelf life of the battery. It should be noted that 0.15 milliliter per day requirement of insulin at 100 units ml described by Dr. S. P. Bessman in "Diabetes Mellitus: Observations, Theoretical and Practical," *J. Ped* 56: 191 (1960). The present apparatus has been built to operate by batteries and occupy less than 50 milliliters of volume.

Although the preferred embodiment has been described in detail using specific commercially available components, these are but examples of piezoelectric elements, electrically operated valves, signal generators and phase shifting circuits. The spirit and scope of this invention are to be limited only by the terms of the appended claims.

What is claimed:

1. A pump having an inlet and an outlet comprising: a variable volume chamber having a single port and at least one piezoelectric wall; a single solenoid valve for controlling the communication of said port to said inlet and outlet; a signal generator; and a transformer having said solenoid valve and said signal generator connected in series on one side of the transformer and said piezoelectric wall connected to the other side of the transformer; the sequential operation of said solenoid valve and said piezoelectric wall needed to produce a pumping effect being produced by the electrical characteristics of the transformer, solenoid valve and piezoelectric wall.
2. The pump of claim 1 wherein said transformer is a step up transformer and said signal generator and said

solenoid valve are connected on the primary and said piezoelectric wall is connected on the secondary.

3. The pump of claim 1 wherein said chamber is founded by two piezoelectric elements, each forming a wall of said chamber.

4. The pump of claim 1 wherein said solenoid valve includes an armature movable between said inlet and said outlet and biasing means for urging said armature to close said outlet.

5. A pump having an inlet and an outlet comprising: a chamber means for holding a medium being pumped and having a port;

a piezoelectric means connected to said chamber means for varying the volume of said chamber means;

a solenoid valve connected between said inlet, said outlet and said port for controlling the communication of said port with said inlet and said outlet; and control means connected to said piezoelectric means and said solenoid valve for electrically activating said piezoelectric means and said solenoid valve in a desired sequence to move said medium from said inlet to said chamber means and from said chamber means to said outlet, past said solenoid valve.

6. The pump of claim 5 wherein said solenoid valve includes an armature movable between said inlet and said outlet and biasing means for urging said armature to close said outlet.

7. The pump of claim 5 wherein said control means includes an oscillator means providing an electric signal of a selectively fixed frequency and the volume of delivery of said pump being proportional to the said selected frequency of said electrical signal of said oscillator means.

8. The pump of claim 7 wherein said frequency is the resonant frequency of said, piezoelectric means.

9. The pump of claim 5 wherein said control means includes an oscillator means for providing periodic voltages, and a transformer, said piezoelectric means being connected across the secondary of said transformer and said solenoid valve being connected in series with said oscillator means across the primary of said transformer, said transformer providing the required sequencing of said piezoelectric means and said solenoid valve.

10. The pump of claim 5 wherein said piezoelectric means is operable for the pump to deliver less than 0.2 microliters per stroke.

11. The pump of claim 5 wherein said chamber means is bounded by said piezoelectric means, said last means being two piezoelectric elements, each forming a wall of said chamber means.

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